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ORIGIN AND CONTROL OF APPLE-BLOTCH CANKERS[1]

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INTRODUCTION

On account of the great significance of the twig cankers as a means of overwintering and source of early infection of the apple-blotch fungus (*Phyllosticta solitaria* E. and E.), knowledge of the mode of origin of these cankers is highly important. Likewise any new light on methods of canker prevention and eradication is much to be desired.

The identity and significance of the blotch cankers were discovered about the same time by Scott and Rorer (*14*)[3] and by Sheldon (*16*), and petiole lesions were described by Sheldon and later by Scott and Rorer (*15*), who made an incidental observation of peculiar interest. They found a large percentage of the fruit buds in an orchard of Limbertwig, Missouri, and Ben Davis trees in Arkansas being killed in midsummer and attributed this in part to the apple-blotch fungus (*15, p. 11*) which according to their observations and cultural work "extended down from diseased leaf petioles into the twigs at the base of the buds, which were soon killed." Apparently, no significance was attached to this phenomenon in connection with the origin of cankers, since they mention spore infection of the twigs.

Lewis (*10, p. 528, 533*), who studied this disease on the Missouri variety in Kansas, states in connection with fruit spur cankers that "the fungus sometimes enters from the leaf stem, and at other times through the new growth just below the bud," and in connection with the importance of leaf infection he mentions the "possible infection of the twig from the petiole."

Roberts (*12, 13*) was able to produce cankers on young twigs and watersprouts by spraying with a water suspension of the spores, but was unable to infect older branches in this way and also was unable to cause infection of twigs by wound inoculation. These results would indicate that cankers are the result of germ tube infection through the uninjured epidermis of very young wood.

A study of the blotch cankers on the Northwestern variety at Mooresville (orchard of Mr. D. B. Johnson) and Knightstown (orchard of Mr. J. B. Hamer), in central Indiana, from 1919 to 1922, and on the Oldenburg variety at Mitchell, in southern Indiana, in 1921 and 1922, indicates that a large percentage of the cankers on twigs are the result of invasion from infected petioles rather than of direct spore infection (*7*). The

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[3] Reference is made by number (italic) to "Literature cited," p. 417-418.

evidence and the obvious deductions are presented herein together with an account of the spray control of canker formation and the eradication of cankers in young orchards.

LOCATION OF CANKERS

One of the outstanding features of the blotch disease in Indiana is that a very high percentage of the cankers on the bearing wood are located at leaf scars (Pl. 1, C, D, F). This condition is very evident on wood not over 3 or 4 years old, but even the older cankers are generally located at leaf nodes and crotches or about the bases of spurs that have developed from dormant buds (Pl. 3, A).

In September, 1921, records taken on 632 cankers on 1920 wood of the lower limbs of Northwestern trees showed that 624, or 98 per cent, were located at leaf scars, and in the fall of 1922 records taken on 96- cankers on 1921 wood of the same trees showed that 963, or 99.5 per cent, were located at leaf scars. Observations made in October, 1921, on 187 Oldenburg twigs of the current season showed that out of 1-- small cankers which had already appeared 61 per cent were located at leaf scars, 16 per cent at the bases of terminal bud scales, and 23 per cent between the scars. Observations made in July, 1922, on the 1921 wood of 80 Oldenburg twigs showed that out of 553 cankers noted 87 per cent were at leaf scars, 5 per cent at the bases of terminal bud scales (Pl. 1, A), and 8 per cent between leaf scars.

On suckers, watersprouts, seedlings, and nursery stock a considerable proportion of the cankers occur between the leaf scars (Pl. 1, B). Counts made on watersprouts showed that 44 out of 50 bore cankers between the leaf scars on growth of the current season. Counts made on suckers of the current season showed that out of 92 lesions noted, 58 per cent were between the scars. On the first-year scion wood of 10 nursery trees 159 blotch cankers were counted, and 58 per cent of these occurred between the leaf scars and the remainder at the scars (Pl. 1, E). It would seem, therefore, that on rapidly growing wood cankers may occur rather generally between the leaf scars.

With respect to location there are four types of canker, (1) at the leaf scars, (2) at the bases of terminal bud scales, (3) at the bases of spurs, and (4) between the leaf scars. Of these the first is the prevalent type on bearing wood and consequently the most important.

DATE OF APPEARANCE OF CANKERS

Since Roberts (*12*) found only young twigs susceptible to spore infection, and since the infection period is early in the season, cankers resulting from direct spore infection should become visible during the first season. This has proved to be the case. The cankers between the leaf scars may be seen the first season and these undoubtedly result from direct spore infection. But in central Indiana the cankers at the leaf scars, which are the prevalent type on bearing wood, do not as a rule become visible until the following spring. It should be noted, however, that in southern Indiana, a larger percentage appear the first season than in the central part of the State.

In the fall of 1920, 35 twigs of 1920 wood on a badly cankered Northwestern tree at Mooresville were tagged and carefully examined. Three small cankers at leaf scars and three cankers between leaf scars were visible. No more of the latter type were evident. On March 22, 1921

o leaf-scar cankers were visible, on April 27 there were 68, by May 20, 95 had appeared, and by September 15, 109 were present on these twigs. Thus the three cankers between leaf scars appeared in the fall of the first season, and 103 out of 109, or 95 per cent, of the leaf-scar cankers did not appear until the second season. Fifty-seven per cent appeared between March 22 and April 27 and previous to the petal-fall period, 25 per cent between April 27 and May 20, and 12 per cent after May 20.

On September 27, 1921, eight twigs on a badly cankered Northwestern tree at Knightstown were tagged and carefully examined. Four cankers were found in the fall, and by April 4, 1922, 6 were visible. By April 25 only 1 more lesion had appeared, but between this date and May 25, 39 cankers became visible and only 3 more appeared later, making a total of 49 cankers, of which 39, or 79 per cent, appeared between April 25 and May 25. All but one, which appeared the first fall, were located at leaf scars.

It is of interest to note that the cankers appeared about a month later in 1922 than those studied at Mooresville in 1921. This difference may be attributed in part to the fact that the spring season at Mooresville is always more advanced than at Knightstown, which is only 45 miles distant and 12 miles farther north. In 1920 the petals fell nine days later at Knightstown than at Mooresville. A more important reason is, however, that the spring of 1922 was later than that of 1921. The petals fell six days later at Knightstown than in 1921. March, 1922, averaged 7.4° F. cooler than March, 1921, and April, 1.4° cooler, according to the records of the Federal Weather Bureau.

The appearance of the majority of these cankers early in the spring of the second season shows that infection must have occurred the previous season and that the mycelium must have been present in the cortex of the twig all winter.

Since the early blotch sprays, as will be shown later, prevent infection, it seems that all spore infection must occur during a rather definite period soon after petal-fall. Consequently, the delayed appearance and the variation in date of appearance of the leaf-scar cankers is difficult to explain upon the basis of direct spore infection. On the other hand, these phenomena are readily explained upon the basis of mycelial invasion of the twig from basal petiole lesions because the mycelium might cross from the petiole to the cortex of the twig at any time during the season. The problem here is quite unlike that found by Wiltshire (*17*) in England in connection with the late fall and early spring spore infection of leaf scars by the apple-canker fungus (*Nectria ditissima*) which acts somewhat as a wound parasite.

The cankers do not appear as gradually enlarging spots but are of considerable size when they first become visible, and the portion which thus makes its appearance is soon delimited by a fissure in the cortex (Pl. 1, C, D, F). The mycelium apparently penetrates a considerable area of bark tissue before its effects become visible.

PREVALENCE OF PETIOLE LESIONS

Petiole lesions (Pl. 1, G, H, I,) are very abundant on the lower limbs of cankered trees. Observations made on unsprayed Northwestern trees in 1920 showed that out of 4,937 leaves examined 1,633, or 33 per cent, bore petiole lesions. In 1921, 5,099 leaves on Northwestern trees were exam-

ined and 2,643 of these, or 52 per cent, bore petiole lesions, and in 1922 84 per cent of the 2,099 leaves examined bore petiole lesions. Out of 1,206 leaves on unsprayed Oldenburg trees examined in 1921, 93 per cent showed petiole lesions and, out of 893 leaves from Ben Davis trees, [illegible] per cent showed petiole infection. From these figures it may be seen that a very high percentage of the leaves on the lower limbs bear petiole lesions. In the majority of cases these lesions are located very near the base of the petiole (Pl. 1, G, H, I,), often in close proximity to the abscission layer.

Incidentally, it is of interest to note that pycnidia containing viable spores are commonly present in these petiole lesions on leaves that have lain over winter on the ground, but no signs of an ascigerous stage have been found.

VISIBLE TWIG INVASION FROM PETIOLE LESIONS

In some cases the lesion at the base of a petiole enlarges until it visibly crosses the abscission layer and invades the tissues of the twig (Pl. 1, J). On the 35 twigs tagged at Mooresville in 1920, there were 155 leaves with basal petiole lesions and in three cases the lesion extended across to the twig tissue. On the eight twigs tagged at Knightstown in the fall of 1921, 65 out of the 105 leaves bore basal petiole lesions and in three cases the lesion had crossed to the twig.

At Mitchell, in the fall of 1921, 129 lesions were noted on Oldenburg twigs of the current season, of which 79, or 61 per cent, were located at leaf scars, and although a large proportion of the leaves at these scars had fallen, 38 per cent of these leaf-scar lesions were obviously extensions from basal petiole lesions.

Thus, in many cases actual twig invasion from petiole lesions may be observed during the current season, particularly in southern Indiana, but as previously noted, the great majority of the twig lesions do not become visible until long after the leaf has fallen.

CORRELATION OF LEAF-SCAR CANKERS AND BASAL PETIOLE LESIONS

In order to determine whether or not cankers appear only at leaf scars to which infected petioles have been attached, 35 twigs on a Northwestern tree at Mooresville were tagged in the fall of 1920 and the location of each leaf with a basal petiole lesion was recorded. There were leaves with basal petiole lesions at 155 scars, and at 109, or 70 per cent, of these leaf scars, blotch cankers appeared, mostly during April and May of the following year, as previously noted. A total of 146 cankers developed on these twigs and 109, or 74 per cent, developed where an infected petiole had been attached. Thirty-two cankers, or 22 per cent were located at scars where no basal petiole infection had been recorded; the origin of these cankers is not clearly understood. It is possible that small petiole lesions were overlooked.

To ascertain more accurately the correlation between petiole lesions and twig cankers, careful records were taken on the leaves on eight twigs of a Northwestern tree at Knightstown on September 27, 1921. There were 107 leaves on these twigs and 76 bore petiole lesions. In each case, the distance of the lower margin of the lowest lesion from the abscission layer was recorded in millimeters and in 49 instances this was less than 3 mm. Cankers developed at 45, or 59 per cent, of the lea

scars where infected petioles had been attached, and at 38, or 77 per cent, of the scars where the petiole lesion had been less than 3 mm. distant from the abscission layer. One canker developed where the petiole lesion was 4 mm. distant, and one where this distance was 7 mm. A total of 48 leaf scar cankers developed, of which 45, or 94 per cent, appeared where an infected petiole had been attached. Two of the other 3 cankers developed at scars where the leaf had fallen before September 27. It has been observed that leaves with basal petiole lesions frequently fall prematurely.

It has also been noted that there is some correlation between the percentage of petiole infection in different trees and the number of cankers per twig observed the next year. For example, in one tree showing 15 per cent petiole infection in 1920, there later appeared 18 cankers per 100 twigs, and in another tree showing 24 per cent petiole infection, there later appeared 30 cankers per 100 twigs. One tree showing 15 per cent petiole infection in 1921 later developed 54 cankers per 100 twigs, another tree with 41 per cent petiole infection developed 137 cankers per 100 twigs, and a third showing 72 per cent petiole infection developed 400 cankers per 100 twigs.

These observations show that there is a close correlation between basal petiole infection and the development of leaf-scar cankers.

INTERNAL INVASION OF LEAF SCAR

While the petiole lesion may be so close to the abscission layer that it visibily extends across to the twig, usually this is not the case (Pl. 1, G, H), and the question at once arises as to the exact manner in which the fungus gains entrance to the twig.

Cultural tests in the fall of 1921 with a number of Northwestern twigs bearing leaves with petiole lesions have indicated how this invasion occurs. The clasping bases of 36 petioles bearing basal lesions were cut off 1 or 2 mm. below the margin of the lesion, sterilized a few minutes in a mercuric chlorid solution, rinsed, and planted in poured plates of potato dextrose agar. The blotch fungus developed from 19, or 53 per cent, of these leaf bases. In one successful isolation the cut was 3 mm. below the margin of the lesion. In certain cases the fungus visibly grew out from both the cut end and the callous end of the leaf base. In another test a petiole segment cut off 1 mm. below a lesion yielded the fungus while the next segment, 3 mm. below the lesion, did not yield the fungus. These tests show that the fungus may progress downward inside of the petiole tissue to a distance of 1 to 3 mm. from the visible margin of the lesion.

A number of leaf scars from which petioles with basal lesions had been removed were cut out of the twigs, sterilized a few minutes in a mercuric chlorid solution, rinsed, and planted in agar plates. Although there had been no visible indication of any infection about any of these scars, 13, or 12.5 per cent, of the 104 thus tested yielded the blotch fungus in culture. In these cases the lower margin of the petiole lesion was within at least 2 mm. of the abscission layer. These tests, made the last of September, show that in a certain percentage of cases the mycelium from a basal petiole lesion grows downward inside of the petiole tissue, penetrates the abscission layer, and invades the leaf-scar tissue of the twig before the leaf falls.

TWIG INVASION FROM BUD SCALES

There is a possibility that some of the twig infection may proceed from bud scales. It has been previously mentioned that out of the 129 cankers noted on Oldenburg twigs of the current season in October, 1921, 21, or 16 per cent, were immediately below terminal buds, and had apparently resulted from bud scale infection and subsequent mycelial invasion of the twig (Pl. 1, A). No tests to prove this theory have yet been made, but the shape and location of such lesions indicate that they may originate in the manner suggested.

LIMB INVASION FROM SPURS

On the Oldenburg variety, encircling blotch cankers often occur on large limbs at nodes where spurs have developed from dormant buds (Pl. 3, A). Whether such a canker is the result of leaf-scar invasion at the time a leaf was borne at that point or the result of a much more recent invasion from a younger canker on the spur, a suggestion made by Mr. R. A. Simpson, is not easily determined. Because of their position in the lower interior part of the tree, these spurs are highly subject to petiole infection and subsequent canker formation. However, cankers are very common at nodes where no spur has developed and must have developed from petiole infection or direct spore infection when that portion of the limb was bearing leaves. It seems likely that both types of limb infection occur and that, if no spur has developed, the canker is very nearly as old as the limb at that point, whereas, if a spur is present, the age of the canker is uncertain.

LONGEVITY OF FUNGUS IN CANKERS

Cultural tests have proved that the blotch fungus may remain alive many years in the advancing margin of the canker where it may continue to produce pycnidia and spores. The diseased tissue is very rapidly invaded by other fungi, but portions of the extreme edge of the purple advancing margin cut out with a scalpel, sterilized a few minutes in a mercuric chlorid solution, rinsed, and planted in agar plates yielded cultures of the blotch fungus, as shown in Table I.

TABLE I.—*Longevity of blotch fungus in cankers*

Variety.	Age of wood.	Number of cankers tested.	Number yielding blotch fungus.
	Years.		
Oldenburg	3	8	[illegible]
Do	4	4	[illegible]
Do	5	6	[illegible]
Transparent	6	5	[illegible]
Oldenburg	7	4	[illegible]
Do	8	2	[illegible]
Do	14	2	[illegible]

Possibly the cankers on the limb 14 years old may have resulted from infected spurs. In the other cases, however, it seems certain that the

age of the canker was about the same as that of the wood. Spore-bearing pycnidia were found in the margins of the cankers on the limbs 7 and 8 years old, and it is apparent that the fungus may remain active in the cankers many years. Anderson (3, *p. 389*) has recently reported similar findings in Illinois.

SPRAY CONTROL OF LEAF AND TWIG INFECTION

By means of spray tests conducted primarily for a study of control of fruit infection and carried out in cooperation with Laurenz Greene and C. E. Baker, of the Purdue University Agricultural Experiment Station, and with certain orchardists, the effect of the blotch sprays upon petiole and twig infection has been ascertained. The control of leaf infection was determined by counts made in the fall at the time of harvesting the apples, but the effect upon canker formation could not be determined until a year later. A more complete account of these spray tests has been published in a station bulletin (7).

Considerable interest has been aroused among growers in the possibility of controlling blotch by means of dormant sprays of concentrated strength such as lime sulphur, 1 to 3. Cultural tests made in 1919 showed that the spores already present in the pycnidia were killed by a dormant spray of lime sulphur, 1 to 3. Guba (9) in Illinois likewise found that the spores in the pycnidia were killed by lime sulphur, 1 to 3, 1 to 5, 1 to 6, and 1 to 8, as well as by copper sulphate, 1 to 6, but observed that the cankers continued to enlarge and produce spores. Extensive field tests in Indiana have shown that dormant sprays have no effect whatever on subsequent leaf infection and canker formation.

The failure of dormant sprays to prevent the development of cankers from infection already present in the leaf scars is shown by the data in Table II, obtained on Northwestern trees at Knightstown. The sprays were applied in the spring of 1921 and the canker counts were made on the 1920 wood.

None of the dormant applications prevented the development of cankers on the sprayed twigs. That dormant sprays have no influence on subsequent leaf and twig infection is shown in the data included in Tables III and V.

The effect of blotch sprays applied two, four, and six weeks after petal-fall in 1920 upon leaf and twig infection in Northwestern trees is shown in Table III. The data on twig infection were obtained the following year. All except the first two trees received a dormant spray of lime sulphur, 1 to 8.

TABLE II.—*Effect of dormant sprays on canker development*

Tree.	Dormant spray.	Twig infection.		
		Number examined.	Percentage infected.	Cankers per 100 twigs.
2R5	Lime sulphur, 1 to 8	103	14.6	18.4
2R3	Lime sulphur, 1 to 3	112	61.6	137.0
2R2	Lime sulphur, 1 to 3	102	62.8	115.0
2R6	Copper sulphate, 1 to 200	142	21.9	30.3

TABLE III.—*Spray control of leaf and twig infection, Knightstown, 1920*

Tree.	Sprays applied 2, 4, and 6 weeks after petal-fall.	Petiole infection.		Twig infection, 1920 wood.		
		Number examined.	Percentage infected.	Number examined.	Percentage infected.	Cankers per 100 twigs.
2R2	None (L. S. 1 to 3, dor.)[a]	757	36	102	63	[illegible]
3R2	None (L. S. 1 to 3, dor.)	697	39	112	62	[illegible]
2R5	None	1,101	15	103	15	[illegible]
2R6	None	1,063	24	142	22	[illegible]
3R3	Bordeaux 4-6-50	954	0.6	114	1.8	[illegible]
2R4	do	1,057	0.1	120	0.8	[illegible]
6R4	do	1,049	0.4	110	0	[illegible]
2R7	do	1,360	0.2	100	0	[illegible]
8R7	do	1,124	0.2	117	0	[illegible]
3R8	Lime sulphur 1 to 40	1,037	0	129	0.8	[illegible]
9R8	do	1,220	0	110	0.9	[illegible]

[a] Lime sulphur, 1 to 3, dormant.

The results in Table III show that the blotch sprays applied 2, 4, and 6 weeks after petal-fall gave a very perfect control of petiole and twig infection, and that twig infection is strictly correlated with petiole infection. The importance of the latter consequently becomes apparent. The control of fruit infection, to be presented in another publication, was in all cases comparable to the control of petiole infection. Lime sulphur appeared to be as effective as Bordeaux, but the following year it proved less so. The dormant spray of lime sulphur 1 to 3 exerted no control whatever.

The effectiveness of the blotch sprays against twig infection is further attested by the fact that cankers were very abundant on the 1919 wood of the same trees in which practically none appeared on wood formed in 1920, the year the blotch sprays were first applied.

At Mooresville, in 1921, information was obtained relative to the ineffectiveness of dusts in controlling petiole infection. These results are presented in Table IV. These results indicate that dusting failed to prevent leaf infection.

TABLE IV.—*Dusts versus spray, Mooresville, 1921*

Applications 2, 4, and 6 weeks after petal-fall.	Petiole infection.	
	Number examined.	Percentage infected.
Sulphur dust	283	[illegible]
Bordeaux dust	184	[illegible]
Bordeaux spray	2,067	[illegible]
None	611	[illegible]

The effectiveness of Bordeaux (3-5-50) blotch sprays against petiole infection was noted by C. L. Burkholder on Ben Davis at Solon in southern Indiana. Out of 893 leaves from unsprayed trees, 88 per cent showed petiole infection, and none of the 2,182 leaves from sprayed trees showed any infection.

The trees at Knightstown recorded in Table III received the same sprays in 1921 and the results are shown in Table V. It should be noted that the twig infection was, of course, determined the following year.

TABLE V.—*Spray control of leaf and twig infection, Knightstown, 1921*

Tree.	Sprays applied 2, 4, and 6 weeks after petal-fall.	Petiole infection.		Twig infection, 1921 wood.		
		Number examined.	Percentage infected.	Number examined.	Percentage infected.	Cankers per 100 twigs.
2R2	None (L. S. 1 to 3 dor.)	771	72.4	101	93	400
3R2	do.	1,154	68.8	101	82	540
3R3	None	1,353	15.1	102	30	54
2R3	None ($CuSO_4$, 1 to 200, dor.).	1,210	41.3	100	38	137
3R3	Bordeaux, 4-6-50	1,340	0.07	100	0	0
2R4	do.	1,349	0	100	0	0
3R4	do.	1,234	0.08	100	0	0
2R7	do.	1,283	0.8	100	0	0
4R7	do.	1,426	0.14	100	0	0
3R8	Lime sulphur 1 to 40	1,599	10.9	106	2.8	4.7
2R8	do.	1,097	5.3	100	5	5

The results shown in Table V indicate that the Bordeaux blotch sprays controlled petiole and twig infection almost perfectly in 1921, while lime sulphur proved distinctly less effective. The dormant sprays did not influence the disease in the least.

The control trees were infected much more seriously than in 1920, but when compared with each other, show the same relative degree of infection as in 1920, a condition to which reference will be made later.

In 1921 lime sulphur 1 to 40 and two strengths of Bordeaux were tested on Oldenburg at Mitchell, with results as presented in Table VI. All except the control trees received a lime sulphur spray at petal-fall.

The results in Table VI show that the weaker Bordeaux as well as the standard strength effectively prevented petiole infection, while the lime sulphur was distinctly unreliable.

In 1922 the two weeks spray was applied three days late at Knightstown and the control of petiole infection was rather poor, as shown in Table VII.

TABLE VI.—*Spray control of petiole infection, Oldenburg variety, 1921*

2, 4, and 6 weeks' spray.	Petiole infection.	
	Number examined.	Percentage infected.
None	1,206	93.0
Bordeaux 4-6-50	1,120	3.3
Bordeaux 2-4-50	1,245	1.7
Lime sulphur 1°	1,196	26.0

TABLE VII.—*Spray control of petiole infection, Northwestern variety, 1922*

Tree.	2, 4, and 6 weeks' spray.	Petiole infection	
		Number examined.	Per cent infected.
4R1	None	1,082	[illegible]
5R1	do	1,017	[illegible]
3R2	Bordeaux 4-6-50	1,230	[illegible]
3R3	do	1,179	[illegible]
2R5	Bordeaux 2-4-50	1,141	[illegible]
2R7	do	1,120	[illegible]
2R6	Lime sulphur 1°	995	[illegible]
3R8	do	1,042	[illegible]

Despite the poor control with Bordeaux, its superiority over lime sulphur is apparent, and the equal effectiveness of the weaker strength is again manifest. Results obtained on Oldenburg fruit in southern Indiana proved that blotch infection started prior to two weeks after petal-fall in 1922 and proved the necessity of an earlier blotch spray in seasons such as 1922, when the blossoming period is prolonged and petal-fall occurs late.

The results presented above show that the Bordeaux sprays which are effective against fruit infection likewise prevent petiole infection, and as a consequence prevent twig infection and canker formation. In this capacity, lime sulphur is not as effective as Bordeaux, but a weaker Bordeaux seems as satisfactory as the standard strength. Under certain conditions an additional spray earlier than two weeks after petal-fall is necessary.

Scott and Rorer (*15*), Roberts (*12*), and others have noted that the sprays which prevent fruit infection also prevent canker formation to a certain degree. These results show how this is brought about and emphasize the necessity of spraying every year, regardless of crop, as Anderson has urged (*2, p. 26; 3, p. 385*), in order to prevent petiole infection and consequent canker formation. Owing to the longevity of the fungus in the cankers, it is probable that it will be necessary to spray continuously for at least seven or eight years to eradicate the fungus from the tree, and one year omitted will result in a crop of new cankers that will necessitate starting the whole campaign over.

DISTRIBUTION OF CANKERS IN OLD ORCHARDS

While a large number of varieties are susceptible to fruit infection, fewer are subject to abundant canker formation and the latter varieties are especially important as harborers and carriers of the disease. Northwestern and Oldenburg are conspicuous examples of this class in Indiana, and also in Illinois according to Anderson (*1*). Among the very susceptible varieties, Benoni, Akin, Missouri, Mann, and Willow are more subject to canker formation than Ben Davis and Stark. Rome and Transparent seem to be more subject to canker formation than to fruit infection. Cankers have been noted sparingly on Grimes, Wealthy, Stayman, Champion, Gideon, Rambo, and Salome, but have not been noted on York, Jonathan, Arkansas, and Winesap, on which varieties occasional fruit infection occurs.

It has been observed among trees of the same variety in the same orchard that blotch is more severe in some than in others and that this relative difference between individual trees remains more or less constant year after year. This phenomenon is illustrated by the data of 1920 and 1921 on four unsprayed Northwestern trees, presented in Table VIII.

TABLE VIII.—*Individuality of trees in degree of infection*

Tree.	Percentage of petiole infection.		Cankers per 100 twigs.	
	1920	1921	1920 wood.	1921 wood.
...R2	36	72.4	115	400
...R2	39	68.8	137	546
...R3	15	15.1	18	54
...R6	24	41.3	30	137

The disease was worse on all trees in 1921 than in 1920, but was consistently worse in the first two trees than in the others and was least severe in the third tree. The correlation is most striking in the canker infection of the two years. In 1920 the relative prevalence of cankers in the four trees may be expressed as 100–119–16–26 and in 1921 as 100–136–13–34. There is a marked individuality of trees with regard to the severity of blotch.

In individual trees it has been noted that cankers are much more prevalent in the lower than in the upper part of the tree, a condition which would naturally result from drip infection in a water-disseminated fungus of this type. In very badly diseased Northwestern trees, only a very few cankers could be found in the topmost branches. The highly susceptible watersprouts and suckers, because of their position in the tree, are subject to abundant infection and should of course be pruned out every year, as Scott and Rorer (*15, p. 21*) and others have recommended. It is impossible to prune out the cankers on bearing wood because of their prevalence in old trees.

CANKERS IN YOUNG ORCHARDS

Because of the large and increasing acreages of young commercial orchards in Indiana, new aspects of blotch control have developed. Blotch cankers have been found very commonly present in young trees of such varieties as Oldenburg, Transparent, and Benoni. In a block of trees at Vincennes, set out in 1918, 98 out of 156 Oldenburg trees, or 63 per cent, and 53 out of 61 Transparent trees, or 88 per cent, bore blotch cankers. The infected trees were scattered here and there and almost all infection was in the form of old cankers on the trunks or large branches. The blotch sprays had been applied during the preceding two years, so practically no young cankers had been formed. There was no evidence of tree-to-tree spread of the disease and all indications were that the original nursery stock had been infected.

In a block of interplanted 2-year-old Ben Davis and Oldenburg trees, 19 out of 36 Oldenburg trees showed blotch cankers while none were noted on the Ben Davis trees. In the same plantation, 3-year-old Oldenburg trees from another source showed very little blotch. In a

block of 53 Rome trees near Paoli, 27 contained blotch cankers. In all these cases the evidence pointed toward introduction of blotch with the nursery stock.

The cankers in young trees were always in the lower parts of the tree. In trees planted in 1917 none were over 6 feet from the ground, but in trees planted in 1915 some cankers occurred considerably higher.

CANKERS ON NURSERY STOCK

M'Cormack (*11, p. 135*) in 1910 reported blotch on nursery stock in Indiana, and Melhus, as reported by Curtiss and Brown (*4, p.* ...), in Iowa has recently found first-year apple grafts seriously injured by blotch and has also found seedlings infected. The occurrence of 159 blotch cankers on the first-year scion wood of 10 trees received from an Oklahoma nursery has been mentioned. Old ankers were also present on the stock below the graft (Pl. 2, C). Blotch cankers have been found on 1-year-old Benoni trees in a nursery row and also on the trees from which the Benoni buds were obtained. Cankers have been found in great abundance on apple seedlings imported from Kansas for budding purposes. After these were budded, cankers occurred both above and below the inserted buds (Pl. 2, A, B) and even on the underground root-bearing portions of the stem.

Nurserymen should guard against blotch by rejecting infected seedlings, and by taking bud-sticks only from sprayed or blotch-free trees, because of the danger of the presence of invisible leaf-scar infection along the buds. The nursery row affords ideal conditions for the spread of a water-disseminated fungus such as this, and nurserymen and seedling growers should apply the blotch sprays annually.

Undoubtedly blotch is carried far and wide and introduced into young orchards with the nursery stock and, as Anderson (*1; 3, p. 389*) has advised, orchardists should reject shipments containing infected trees.

CANKER ERADICATION IN YOUNG ORCHARDS

The facts presented relative to the presence of blotch on nursery stock and on scattered trees in young orchards, as well as the greater incidence of cankers in the lower parts of the trees and the constant differences in severity of the disease in individual trees, assist one in interpreting the progress of the disease in an orchard. Starting with the trees which were originally infected in the nursery, it would seem that the disease slowly progresses upward by the splashing of spores from the older cankers to leaves higher up until by the time the tree comes into bearing, there are cankers high enough to provide a "cone" of drip and splash infection inclusive of most of the tree. Even though considerable tree-to-tree spread of infection occurs in old orchards, this appears to be uncommon while the trees are young and widely separated, and, to a certain extent, each tree continues to present a more or less independent pathological picture in which the severity of the disease depends upon the early presence of cankers and their subsequent rate of multiplication. Furthermore there would seem to be little, if any, dissemination from one orchard to another.

On the basis of this theory, the elimination of the disease from a young orchard should greatly reduce, if not entirely obviate, the future blotch menace in that orchard. Such a result may be accomplished, it is believed, by two measures, the annual application of the blotch sprays

at least for a few years to prevent the formation of new cankers, as Anderson (*2, p. 26; 3, p. 385*) has recommended, and the eradication of the old cankers by pruning and excision. The effectiveness of the sprays in canker prevention has been shown, and the recommendation of Scott and Rorer (*15*) and others that cankered twigs be pruned out is particularly applicable in the case of young trees.

The feasibility of canker eradication in young trees has been tested in cooperation with Mr. R. A. Simpson at Vincennes, Ind., and it has proved to be a comparatively simple process. Many cankers were removed by pruning out spurs and smaller limbs, and the cankers on the trunks and larger limbs were cut out with a sharp knife. The fungus does not penetrate much more than halfway through the bark and the diseased bark tissue can be shaved off without cutting deeply enough to injure the underlying cambium layer (Pl. 3, A, B). A number of cankers were excised from Oldenburg trees in the spring of 1921 and the wounds healed rapidly and perfectly. A few cases of marginal renewal of fungous growth showed that it is necessary to cut about 1 cm. in advance of the visible margin of the canker in order to remove all of the mycelium. This is particularly true at the sides since the canker tends rapidly to encircle the limb (Pl. 3, A). It is also essential to cut deeply enough to remove all of the discolored tissue.

In a block of Oldenburg and Transparent trees set out in 1918, the blotch cankers were removed early in April, 1922. Cankers were found in 58 of the 156 Oldenburg trees and from these about 59 cankered limbs or spurs were pruned out and 134 cankers were excised. Cankers were found in 48 of the 61 Transparent trees, mostly on the trunks, and from these trees three cankered limbs were pruned and 145 cankers shaved off. Since this plot had received the blotch sprays the previous year, very few new cankers appeared.

Reinspections of this plot early in November and in April, 1923, showed that 40 per cent of the trees operated upon were free from cankers. The wounds had become mere surface scars in the bark and no injury to the trees was noticeable (Pl. 3, C). A coating of melted paraffin had been applied to some of the wounds but proved to be unnecessary. However, about 300 cankers scattered among 110 trees had been overlooked and were removed. The need of more than one reinspection and repetition of the process is apparent. Fire blight was prevalent when the blotch cankers were cut out, but no cases of infection of the cuts were found.

In a smaller block of 34 Oldenburg trees planted in 1920, 19 bore cankers and from these trees 61 cankers were removed on April 26. On November 9, 50 per cent of the trees operated upon were free of infection, but four cases of marginal renewal of fungous growth and 44 cankers were found. Most of the latter were on 1921 wood, the result of a failure to apply the blotch sprays in 1921, and were not visible in April when the first inspection was made. This emphasizes further the necessity of a reinspection to detect cankers overlooked or invisible at the time of the first operation.

In an orchard near Paoli, Ind., 27 out of a group of 55 young Rome trees contained cankers and from these trees 23 cankered limbs were pruned and 75 cankers were shaved off. In a block of 24 Transparent trees about 10 years old, 20 bore cankers and from these trees 92 cankered limbs were pruned and 116 cankers excised. By fall these excision wounds were mere scars in the bark.

In April, 1922, canker eradication was carried out on an extensive scale by Mr. Simpson in an orchard containing about a thousand Oldenburg trees planted in 1917 and sprayed for blotch in 1920, 1921, and 1922. In November 214 of these trees were examined (Pl. 3, C) and it was found that more than half of the 152 trees operated upon were free from infection. Cankers had been overlooked in 78, or about one-third of the trees and a very few cases of marginal renewal of fungous growth were found. However, the great majority of the cankers had been removed and one or two repetitions of the process should practically eliminate the disease since the sprays have prevented the formation of new cankers.

Other owners of young orchards in the Vincennes region have cut the cankers from their trees and the method bids fair to be widely adopted. A Kansas orchardist, William Freienmuth (5), recently reported success in cutting out blotch cankers in a 20-year-old orchard of Ben Davis and Missouri and strongly advocates canker eradication. He began his work in the fall of 1919 and employed somewhat the same method advised above except that the wounds were treated with a Bordeaux wash.

It seems advisable to cut out cankers early in the spring because the absence of leaves facilitates detection of the cankers and because the wounds heal most rapidly at that time. No disinfectant or wound dressing has been necessary on young trees. This operation is harmless and inexpensive and removes a dangerous source of blotch infection in young orchards.

SUMMARY

(1) Blotch cankers on bearing wood are usually located at leaf scars. On suckers, watersprouts, nursery stock, and seedlings, cankers occur at and also between the leaf scars. Cankers also occur at the bases of terminal bud scales and at the bases of spurs.

(2) Cankers at the leaf scars as a rule become visible during April and May of the second season in central Indiana.

(3) Basal petiole lesions are extremely prevalent in badly diseased trees.

(4) Cases have been noted in which the basal petiole lesions visibly extended across the abscission layer to the twig tissue.

(5) Cankers appear at leaf scars to which leaves with basal petiole lesions were attached, particularly where the edge of the petiole lesion was not more than 2 or 3 mm. from the abscission layer.

(6) Cultural tests have shown that the fungus from a basal petiole lesion grows down inside the petiole to a distance of 2 or 3 mm. and even farther and in many cases crosses the abscission layer into the twig tissue before the leaf falls.

(7) Cankers may originate from terminal bud-scale infection, and cankers on large limbs about the base of a spur may have developed from a canker on that spur.

(8) In general, the age of the canker is only slightly less than that of the wood in which it is located. The blotch fungus has been found alive in the margins of cankers on wood up to 7 and 8 years old and in one case on wood 14 years old.

(9) The blotch sprays which prevent fruit infection also prevent petiole infection and as a consequence canker formation. The prevalence of cankers is proportional to the amount of previous petiole infection

(10) Dormant sprays of concentrated lime sulphur (1 to 3) did not influence canker development, although spores already present in the pycnidia may have been killed. Subsequent petiole infection was not checked.

(11) Sulphur and Bordeaux dusts were unreliable in the prevention of petiole infection and canker formation.

(12) Bordeaux 4–6–50, and 2–4–50 as well, applied 2, 4, and 6 weeks after petal-fall prevented petiole infection and subsequent canker formation. Under certain conditions an earlier spray application is necessary. Lime sulphur 1° or 1 to 40 was not as reliable as Bordeaux.

(13) In old orchards certain varieties are more severely cankered than others and are harborers of the disease. Cankers are most abundant in the lower parts of the tree. Individual trees show more or less constant differences year after year, in the degree of infection.

(14) Cankers have been found on a considerable percentage of the trees in young orchards, especially Oldenburg, on the trunks and older limbs. The infected trees were scattered and there was evidence of disease introduction with the nursery stock and very little evidence of tree-to-tree spread in young orchards.

(15) Cankers have been found in great abundance on nursery stock on both stock and scion and on seedlings used for budding purposes. The evidence indicated that the nursery row afforded ideal conditions for the spread of blotch.

(16) It has proved feasible to eradicate the blotch cankers from young orchards by pruning cankered spurs and small branches and by excising the cankers on the larger limbs. The cankers are shallow and can be shaved off with a sharp knife in the early spring without injury to the underlying cambium. To remove all the mycelium the cuts must be deep enough to remove all the discolored tissue and must extend about 1 cm. beyond the visible margin of the canker. Healing occurs rapidly and no disinfectant or wound dressing has been necessary.

(17) By canker eradication and annual application of the blotch sprays to prevent the formation of new cankers, it seems entirely possible that the future blotch menace in young orchards may be avoided.

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PLATE 1

A.—Apple-blotch canker at base of terminal bud scale.
B.—Canker between leaf scars on watersprout.
C, D, F.—Cankers at leaf scars on bearing wood.
E.—Leaf-scar canker on nursery stock.
G, H, I.—Basal petiole lesions. In I the lesion has visibly crossed to the twig

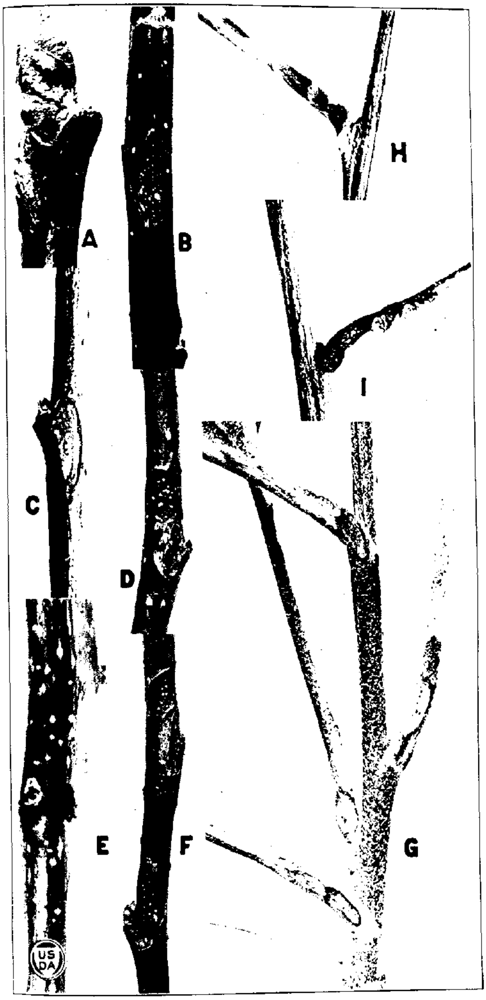
A
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PLATE 2

A.—Apple-blotch cankers on a budded seedling below the inserted bud.
B.—Cankers on a budded seedling, above and below the inserted bud.
C.—Cankers on a nursery tree above and below juncture of stock and scion.

PLATE 3

A.—Encircling type of apple-blotch canker on Oldenburg at a node.

B.—Canker excision. Canker shown in A, cut out with a sharp knife. The cut is not deep enough to injure the cambium.

C. Results of canker excision in young Oldenburg tree. Cankers cut out in April, photographed in November. Wounds healed perfectly. Paraffin coating was unnecessary. One canker was overlooked, as indicated by the fresh cut.


A
B
C

DETERMINATION OF THE SURFACE AREA OF CATTLE AND SWINE[1]

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HISTORICAL

The modern conception of nutrition may very properly be ascribed to the classic investigations of Lavoisier (*6*).[3] He recognized that the production of animal heat is an oxidation process, and conducted experiments to demonstrate his views.[4] It was many years before it became established that the oxidative processes alone could entirely account for all the heat produced by the animal body. In the meantime, however, rough comparisons were made of the heat produced by different individuals, and it soon became apparent that the amount of heat produced under comparable conditions was not proportional to the weights of the subjects investigated.

It is sufficient for the present to say that as yet no entirely satisfactory method has been devised for the comparison of heat production of animals of different sizes, but in 1848 Bergmann (*3*)[5] made a suggestion that has found wide application. He expressed the belief that the relatively high heat production of small animals per unit weight is due to their relatively greater surface area. This view was given strong support by the classic researches of Regnault and Reiset (*10*). Their studies were concerned largely with the respiratory exchange, as manifested by various species under diverse conditions. They believed that the chemical changes within the body are so complicated that it would be impossible to calculate the resulting heat production (*10, p. 513*). As a result of the observations of these collaborators, however, it was established that the oxygen consumption of animals is not proportional to their weights, and that the smaller the animal the higher the oxygen consumption per unit weight (*10, p. 473*). The sparrow, for example, in unit time consumes nearly 10 times as much oxygen per kilogram live weight as a fowl. Obviously, the heat production per kilogram would have a similar ratio. Their explanation was that the smaller animals have a relatively greater surface area. While their reasoning on that point is faulty, at least in part, their statement of the facts is substantially correct.

Apparently, no actual measurements of the surface area of living beings were made until 1879, when Meeh (*8*) published such measurements on man and suggested that the surface area of any individual could be calculated by the use of a formula. His formula is based on the mathematical relation that exists between the surfaces and volumes of similar

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[2] The data for this paper were taken from the thesis of Charles I. Skouby, presented at the University of Missouri in partial fulfilment of the requirements for the degree of master of arts.

[3] Reference is made by number (italic) to "Literature cited," pp. 429-430.

[4] Cited by Lusk (*7, p. 33*).

[5] Cited by Benedict (*2*).

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solids—that is, the surfaces are proportional to the two-thirds powers of their volumes. If the specific gravity were the same in each case, then the surface areas would also be proportional to the two-thirds powers of the weights. The formula of Meeh may be expressed as follows: $S = KW^{\frac{2}{3}}$. S is the surface area in square centimeters, W is the weight in grams, and K is the constant 12.312 for adults and 11.9 for children. According to Meeh's calculation the extreme variations were ± 7 per cent.

A few years later Rubner (*11*) measured the surface area of a number of dogs and determined their heat production under comparable conditions. All the animals were mature, in the condition of inanition, and the surrounding temperature was approximately the same. The heat produced is given in 24-hour periods, measured at a temperature of 15° C.

TABLE I.—*Heat production in relation to body weight and surface area*

No. of dog.	Average body weight.	Calories liberated—	
		Per kilo body weight.	Per square meter surface area.
	Kgm.		
I	31.20	35.68	1,036
II	24.00	40.91	1,112
III	19.80	45.87	1,207
IV	18.20	46.20	1,097
V	9.61	65.16	1,183
VI	6.50	66.07	1,153
VII	3.19	88.07	1,212

The heat production per kilo varied widely, but was quite constant per square meter of body surface.

Some years later Rubner (*12*) conclusively demonstrated that the oxidation processes within the body are alone sufficient to account for the entire heat production. He constructed a respiration calorimeter and made seven experiments on dogs. These covered in all a period of 45 days, and the average heat production determined directly from the calorimeter differed from that computed from the respiration apparatus by less than one-third of 1 per cent.

Thus, after the lapse of more than one hundred years following the original pronouncement of Lavoisier (*6*), it was conclusively demonstrated that the oxidation processes alone could account for all the animal heat produced. It was shown clearly that the quantity of heat produced was not proportional to the weights of the animals, but it became reasonably certain that the quantity of heat does bear some direct relation to the surface area of the subjects investigated. Accordingly, it has become the practice of many investigators when comparing the energy transformations of animals of different weights, to compare the heat production per unit of surface area.

Before dismissing the historical phase of the subject, mention should be made of the fact that Benedict (*2*) has sharply challenged the practice of calculating heat production per unit of surface area, and concludes "that the metabolism or heat output of the human body, even at rest, does not depend on Newton's law of cooling and is therefore not proportional to the body surface." Benedict's statement applies of course

to the animal body as forcefully as to the human body. The heat output does not depend on Newton's law of cooling and it is not proportional to the body surface under all circumstances. In the opinion of the writers, however, this method of computing energy transformations has great advantages over any hitherto proposed.

Whether Benedict's objection is valid or not, in practice the animal husbandryman has some difficulty in comparing the metabolism of his experimental animals per unit of surface area. The proper constants have been determined in only a few instances, so it has been impossible to calculate the surface areas of the ordinary farm animals with any degree of accuracy. That difficulty was avoided, however, by making the calculations on the basis of a uniform weight, as was the practice of Armsby (*1, p. 260*). According to the Meeh formula, this means that the surfaces of animals are proportional to the two-thirds powers of their weights. If the formula is correct, that method would be satisfactory. As a matter of fact, it soon became evident that the formula may give very erroneous results. Trowbridge, Moulton, and Haigh (*14*) published a number of measurements of the surface area of cattle, and calculated the constant for the Meeh formula, expressed as follows:

$$K = \frac{S}{W^{\frac{2}{3}}}$$

Of the cattle investigated, the variations were extreme, and the constants varied from 7.319 to 10.474. The constant was greatest for the thinner and younger animals and least for those older and fatter.

Some time later Moulton (*9*) developed two formulae, differing somewhat from that of Meeh. The formula for fat cattle is:

$$A = 0.158\ W^{\frac{5}{9}}$$

and for other animals:

$$A = 0.1186\ W^{\frac{5}{8}}$$

A is the surface area in square meters, W is the empty weight in kilograms.

The work of Trowbridge, Moulton, and Haigh (*14*) and of Moulton (*9*) makes it clear that a simple formula of the Meeh type is not applicable to cattle. At about the same time that their work was published, E. F. and D. Du Bois (*4*) and collaborators had reinvestigated the formula as applied to man, and showed that it leads to serious errors. They (*5*) finally devised their "height-weight" formula which seems to be quite exact. The formula is:

$$A = W^{0.425} \times H^{0.725} \times C$$

A is the surface area in square centimeters, H the height in centimeters, W the weight in kilograms, and C the constant 71.84. The error was estimated to be ± 5 per cent as a maximum. The error with the Meeh formula as applied to their subjects (*13*) ranged from 4.9 to 38.0 per cent.

It is evident from the work of the Du Boises on man and of Moulton on cattle that the surface area can not be accurately calculated as a power function of the weight. Accordingly, we have attempted to devise a formula that would permit a more accurate calculation of the surface area of cattle and swine. The "height-weight" formula of Du Bois was taken as a guide.

EXPERIMENTAL

We wished to know the surface area of some of our experimental steers, under observation at the time, so our first measurements of cattle were made on living animals. The first step was to prepare an inelastic mold of one-half the body, that is, of one side. This was accomplished by pasting strips of strong manila paper, gummed on one side, to the hair of the animal, and building up on this foundation until the mold was rigid enough to be handled. Before it was removed the median line was marked so that when trimmed the mold represented exactly one-half the surface area. The mold was usually made in four parts. Each leg made up a part, the shoulder, neck, and head made up another, and the body and hind quarter made up the fourth. The outside of the ear was also measured and the area multiplied by two. The steers were gentle and accustomed to being handled, so with care it was possible to obtain a very accurate mold. When dry it was cut into pieces that would lie flat. These pieces were traced on blue-print paper, and the tracings cut out and weighed. The weight of the paper per square centimeter was determined, and then it was a simple matter to calculate the surface area of the animals. Before adopting this method we assured ourselves that the paper used was sufficiently uniform for our purpose.

The method employed for measuring the surface area of the slaughtered cattle consisted in tracing the outline of the entire hide on a large sheet of paper made by pasting strips of heavy wrapping paper together. With a little care the hide could be made to lie flat and an accurate tracing obtained. The area was determined by drawing rectangles and triangles on the tracing of the hide and measuring these. This method also was used for determining the surface area of the swine. In most cases only the hide from half of these animals was measured, that from the right side of the body.

In one case we had an opportunity to compare the two methods of determining the surface area of cattle. Steer No. 528 was killed not long after his surface area had been determined by use of the mold. The hide was removed and measured, and the two methods compared.

Area determined from hide	64,344 sq. cm.
Area determined from mold	64,028 sq. cm.
Difference	316

The difference in this case is less than 0.5 per cent of either determination.

MEASUREMENTS TAKEN

A number of measurements were taken on these animals, but the only one used was the "length of body." The length of body of cattle was taken as the distance measured with a tape from the point of the withers to the end of the ischium. The length of body of swine is the distance as measured with a tape from the point of the withers to the root of the tail.

The chief difficulty encountered in using the formula lies in the uncertainty as to the exact position of the "point of withers." We attempted to use some other measurement, but failed to find one more satisfactory. It is impossible, of course, to secure any cooperation from animals in taking these measurements, and, if any portion of the neck is included, the position in which they stand affects very materially the result.

Obviously, the posture of the animal has little or no effect on the measurement we have chosen. Furthermore, we do not believe that the uncertainty as to the location of the point of withers will cause any real difficulty. The measurements from which our formula was derived were taken by several observers, and so represent the probable range of variation in the selection of those points. Our calculated results would hardly agree so closely with the measured area if these variations are of great moment. In order to indicate more clearly the location of these points they have been shown on Plate 1.

In anatomical terms the "point of the withers," as we have determined it, seems to lie directly above the juncture of the second and third thoracic vertebrae. The end of the ischium is the tuber ischii, commonly called the pin bone. The point of the withers of swine, as we have taken it, lies above the juncture of the first and second thoracic vertebrae. The root of the tail is, of course, the point where tail and body join.

WEIGHT

Besides the "length of body," also the weights of the animals were used in developing the formula. This is simply the weight of the animal taken at the time the surface area was measured. Neither food nor water was withheld from the animals before weighing.

DESCRIPTION OF ANIMALS

The cattle were in practically all cases of beef breeding variety and varied from scrubs to the purebred. They varied in age from about 6 weeks to 8 years, and in condition from very thin to very fat. The weights range from 55 to 842 kgm., and the length of body ranges from 61 to 172 cm. The data include four females, two heifers, and two dry cows.

The swine were purebreds, including Poland China, Duroc Jersey, and Yorkshire breeds. They varied in age from 3 weeks to over 3 years, and in condition from very thin to very fat. The live weights ranged from 2.5 to 178.1 kgm., and the length of body ranged from 24 to 132 cm. Both barrows and females were included. The data used in developing the formula for cattle are given in Table II and for swine in Table III.

TABLE II.—*Data used for development of formula for cattle*

No. of animal.	Live weight.	Length of body.	Surface area as measured.
	Kgm.	*Cm.*	*Sq. cm.*
1 [a]	568	156	55,407
2 [b]	550	143	50,583
3 [a]	486	140	47,721
4	468	138	46,521
5 [b]	406	132	45,171
6	55	61	12,466
7	131	95	23,581
8	500	132	49,900
528	668	172	64,028
572	408	126	45,176
573	318	125	41,140
571	387	136	47,138
574	276	125	38,236
575	302	130	40,236
577	511	150	55,664
578	420	136	48,957
579	480	150	53,190
585	432	145	49,046
503 [c]	271	124	36,143
509	439	147	49,701
197	482	152	52,810
507	457	153	50,175
502	506	152	51,038
541	324	111	38,036
527	842	162	66,343
515	743	150	58,846
48	809	155	62,038
501	883	152	64,635
592	213	129	34,345
558	108	87	20,189
538	181	105	29,211
524	362	145	46,417
500	457	153	54,148
540	158	99	26,068
595	265	125	36,555
525	305	131	39,955
523	381	136	46,827

[a] Dry cow.
[b] Heifer.
[c] The weights and surface areas of all animals below the line were published by Trowbridge, Moulton, and Haigh (*14*).

TABLE III.—*Data used for development of formula for swine*

No. of animal.	Live weight.	Length of body.	Surface area as measured.
	Kgm.	*Cm.*	*Sq. cm.*
15B	44.9	77	10,972
60B	41.1	72	10,625
3B	75.0	87	14,759
6B	74.1	85	14,702
53B	90.0	96	16,207
12B	90.0	93	16,147
35S	101.8	100	17,384
40S	121.0	95	17,365
33B	134.0	103	19,330
10B	142.0	94	19,126
100	21.1	51	6,744
101	5.0	31	2,712
102	3.6	31	2,242
103	10.3	38	4,094
104	178.1	132	27,215
105	3.1	25	1,999
106	2.5	24	1,743
1 [a]	101.3	79	14,850
2	114.1	84	16,460
5	88.2	81	14,576
6	118.2	84	16,528
8	111.0	85	15,887
9	127.7	87	17,384
10	101.0	72	14,204

[a] We are indebted to the Department of Agricultural Chemistry for all data concerning the animals below the line.

Many of the steers described in the publication of Trowbridge, Moulton, and Haigh (*14*) were measured, and these animals, 19 in all, are included with our data. These same investigators also determined the surface area and took measurements of seven swine, and we have availed ourselves of the opportunity to use this material. Unfortunately for our purpose, the length of the body as recorded by them extended forward to the poll. In order to use their data we examined similar animals in our herd and estimated that for swine of that length the measurement of Trowbridge, Moulton, and Haigh is 15 cm. longer than ours. We have, therefore, arbitrarily deducted 15 cm. from the length of body as they measured it, in order to make their measurements comparable to ours. An element of uncertainty is thus introduced with these seven animals.

CALCULATION OF FORMULA

The method of calculation was quite simple, though the process proved to be rather laborious. The observed values of the surface area, live weight, and length of body, were put in the form of an equation.

$$S = W^x \times L^y \times K, \text{ or}$$

$$\text{Log } S = x \log W + y \log L + \log K$$

Since there are three unknowns, x, y, and K, we formed three simultaneous equations in a number of different combinations and solved for

the unknown values. We were disappointed in one respect—the values obtained for the exponents were not as uniform as we had hoped. Our final procedure, therefore, was to take the values most frequently occurring and by actual trial to determine which gave the least variable values for K. The value then assigned to K was the mean of the extremes. The equation finally chosen is:

$$S = W^{.4} \times L^{.6} \times K$$

K is 217.02 for cattle and 175 for hogs. S is the surface area in square centimeters. W is the weight in kilograms, and L is the length of the body in centimeters. This formula is, of course, identical in principle with the Du Bois height-weight formula for man.

In order to test the relative usefulness of our method, the surface areas of our animals have been calculated both by the length-weight formula and the Meeh formula. The calculations for cattle include also the formula of Moulton as developed for thin animals. His calculations were based on the empty weight, so we assumed that the formula would apply to the live weight if a suitable constant were chosen. The constant selected is 1,081. The Moulton formula for fat animals was not used because we were not certain that any of our animals were sufficiently fat to be classed in that group. It would seem that the possibility of error in judgment as to which to use is an element of weakness in the Moulton formulae, though we doubt whether it would lead to a gross error.

TABLE IV.—*Surface area as measured and as calculated for cattle*

No. of animal.	Surface as measured.	Surface as calculated.					
		$S = W^{.4} \times L^{.6} \times K_1$ [a]		$S = W^{2/3} \times K_2$ [a]		$S = W^{5/8} \times K_3$ [a]	
		Area.	Error.	Area.	Error.	Area.	Error.
	Sq. cm.	*Sq. cm.*	*Per cent.*	*Sq. cm.*	*Per cent.*	*Sq. cm.*	*Per cent.*
1	55,407	56,770	+2.5	55,692	+0.5	56,924	+2.7
2	50,583	53,193	+5.2	54,509	+7.8	55,790	+10.3
3	47,721	49,984	+4.8	50,194	+5.2	51,638	+8.2
4	46,521	48,812	+4.9	48,947	+5.2	50,434	+8.4
5	45,171	44,900	−0.6	44,522	−1.4	46,148	+2.2
6	12,466	12,702	+1.9	11,743	−5.8	13,230	+6.1
7	23,581	23,444	−0.6	20,944	−11.2	22,758	−3.5
8	49,990	48,801	−2.4	51,152	+2.3	52,563	+5.2
528	64,028	64,229	+0.3	62,050	−3.1	62,996	−1.6
572	45,176	43,750	−3.2	44,668	−1.1	46,290	+2.5
573	41,140	39,411	−4.2	37,831	−8.0	39,613	−3.7
571	47,138	44,843	−4.9	43,122	−8.5	44,786	−5.0
574	38,236	37,240	−2.6	34,422	−10.0	36,257	−5.2
575	40,236	39,525	−1.8	36,551	−9.2	38,355	−4.7
577	55,664	53,152	−4.5	51,900	−6.8	53,283	−4.3
578	48,957	46,336	−5.4	45,540	−7.0	47,136	−3.7
579	53,190	51,839	−2.5	49,780	−6.4	51,240	−3.7
585	49,046	48,698	−0.7	46,403	−5.4	47,973	−2.2
503	36,143	36,791	+1.8	34,005	−5.9	35,846	−0.8
509	49,701	49,418	−0.6	46,904	−5.7	48,458	−2.5
197	52,810	52,340	−0.9	49,919	−5.5	51,372	−2.7
507	50,175	51,438	+2.5	48,177	−4.0	49,690	−0.9
502	51,038	53,366	+4.6	51,562	+1.0	52,956	+3.8
541	38,036	36,975	−2.8	38,303	+0.7	[b] *40,079*	*+5.4*
527	66,343	67,973	+2.5	72,405	+9.2	[b] *72,803*	*+9.7*
515	58,846	61,737	+4.9	66,612	+13.2	[b] *67,327*	*+14.4*
48	62,038	65,145	+5.0	70,500	+13.6	[b] *71,006*	*+14.4*
501	64,635	66,679	+3.2	74,737	+15.6	[b] *74,098*	*+15.0*
592	34,345	34,214	−0.4	28,961	−15.7	30,836	−10.2
558	20,189	20,586	+2.0	18,415	−8.8	20,170	0.0
538	29,211	28,332	−3.0	25,982	−11.1	27,853	−4.6
524	46,417	45,373	−2.2	41,245	−11.1	42,955	−7.5
500	54,148	51,437	−5.0	48,177	−11.0	49,690	−8.2
540	26,068	25,902	−0.6	23,732	−9.0	25,585	−1.8
595	36,555	36,639	+0.2	33,502	−8.4	35,347	−3.3
525	39,955	39,864	−0.2	36,792	−7.9	38,593	−3.4
523	46,827	44,564	−4.8	42,675	−8.9	44,351	−5.3

[a] Constants: $K_1 = 217.02$; $K_2 = 812$; $K_3 = 1,081$.

[b] These animals were very fat when measured, so this formula is not expected to apply to them. They are included merely to complete the table.

TABLE V.—*Surface area as measured and as calculated for swine*

No. of animal.	Surface as measured.	Surface as calculated.			
		$S=W^{.4}\times L^{.6}\times K$[a]		$S=W^{2/3}\times K$[b]	
		Area.	Error.	Area.	Error.
	Sq. cm.	*Sq. cm.*	*Per cent.*	*Sq. cm.*	*Per cent.*
B	10,972	10,860	−1.0	9,816	−10.5
B	10,625	10,061	−5.3	9,254	−12.9
[illegible]	14,759	14,344	−2.8	13,818	6.4
[illegible]	14,702	14,081	−4.2	13,708	−6.8
B	16,207	16,372	+1.0	15,605	3.7
B	16,147	16,053	−0.6	15,605	−3.4
S	17,384	17,625	+1.4	16,933	−2.6
S	17,365	18,314	+5.5	19,009	+9.5
B	19,330	20,025	+3.6	20,347	+5.3
B	19,126	19,401	+1.4	21,148	+10.6
[illegible]	6,445	6,270	−2.6	5,933	−12.0
[illegible]	2,712	2,614	−3.6	2,272	−16.2
[illegible]	2,242	2,292	+2.2	1,825	−18.6
[illegible]	4,094	3,936	−3.9	3,678	−10.2
[illegible]	27,215	26,040	−4.3	24,596	−9.6
[illegible]	1,999	1,898	−5.0	1,652	−17.4
[illegible]	1,743	1,699	−2.5	1,431	−17.9
[illegible]	14,850	15,271	+2.8	16,885	+13.7
[illegible]	16,460	16,616	+0.9	18,278	+11.0
[illegible]	14,576	14,666	+0.6	15,396	+5.6
[illegible]	16,528	16,852	+2.0	18,714	+13.2
[illegible]	15,887	16,551	+4.2	17,946	+13.0
[illegible]	17,384	17,751	+2.1	19,704	+13.3
[illegible]	14,204	14,425	+1.6	16,851	+18.6

[a] K = 175.   [b] K = 777.

It will be noted from Tables IV and V that when the surface areas were calculated by using the two-thirds power of the weight, the maximum error with cattle is ±15.6 per cent and with swine ±18.6 per cent. The constants chosen were 812 for cattle and 777 for swine. The "length-weight" formula gives a maximum error of less than ±5.5 per cent with either cattle or swine.

The Meeh formula gives a positive error with the fat animals and a negative error with the thin ones. The errors in calculating the surface area of cattle by the length-weight formula could not be definitely correlated in any such manner with the condition of the animal. In the case of the swine the tendency of the fat animals to give a positive error and of the thin animals to give a negative error is quite distinct. We are inclined to believe this is due to the fact that as the hogs became fatter, the thickening of the subcutaneous fat pushed the root of the tail farther back, and so made the length of body measurement too long. Whatever the cause may be, we do not consider that difficulty of any importance.

The Moulton formula, which applies only to cattle, gives better results than that of Meeh, but is less accurate than the "height-weight" formula. Five of the animals, No. 541, 527, 515, 48, and 501, were very fat when the surface areas were measured, so according to Moulton the exponent 5/9 and not 5/8 should be used in these cases. The five have been included with the others, but are disregarded when making comparisons. The maximum error obtained in the remaining cases is then ±10.2. It may be suggested that some of the animals were sufficiently fat so that the exponent 5/9 and not 5/8 should be used. This may be true, but the usefulness of the formula is diminished if it is necessary to know the correct result before deciding which exponent to use.

There may be some doubt attached to the use of the Moulton formula, since it was originally derived from the empty weight of the animals. As stated previously (see Table IV), we changed the constant and applied it to the live weight. In order to make the comparison as rigorous as possible, we have applied the formula as originally devised to the empty weight of the steers described by Trowbridge, Moulton, and Haigh (14). These calculations appear in Table VI.

TABLE VI.—*Calculated surface areas of steers measured by Trowbridge, Moulton, and Haigh*

No. of steer.	Group and condition.	Empty weight.	Surface as measured.	Surface as calculated.			
				$S=.1186\ W^{5/8}$.		$S=.1580$ [a] W[illegible].	
				Surface.	Error.	Surface.	Error.
		Gm.	*Sq. cm.*	*Sq. cm.*	*Per cent.*	*Sq. cm.*	*Per cent.*
547	I	171,448	27,692			27,532	−0.6
541	I	288,297	38,036			36,749	−3.4
594	I, fat	247,517	32,850			33,759	[illegible]
532	I	459,025	50,419			47,584	−5.6
593	I, good	317,909	38,884			38,800	[illegible]
504	I	475,854	48,225			48,546	+0.7
515	I, very fat	671,917	58,846			58,801	+0.1
121	I, fat	508,513	50,104			50,369	[illegible]
527	I, very fat	786,005	66,343			64,155	−3.3
513	I, very fat	772,785	61,633			63,553	−3.1
501	I, very fat	814,914	64,635			65,454	−1.3
48	I, very fat	744,708	62,038			62,260	+0.4
554	II	78,071	17,343	18,067	+4.2		
550	II	121,112	22,144	23,773	+7.4		
538	II	158,911	29,211	28,171	−3.6		
503	II	236,429	36,143	36,112	−0.1		
597	II, maintenance	302,793	42,781	42,150	−1.5		
523	II	337,803	46,827	45,134	−3.6		
507	II	418,896	50,175	51,630	+2.9		
526	II	427,995	54,751	52,329	−4.4		
197	II, good condition	444,750	52,810	53,599	+1.5		
502	II	444,424	51,038	53,575	+5.0		
511	II	493,877	60,054	57,226	−4.7		
558	III	89,999	20,189	19,746	+2.2		
540	III	137,726	26,068	25,761	−1.2		
531	III	192,005	34,083	31,707	+7.0		
591	III, very thin	190,043	33,177	31,502	−5.1		
592	III, extremely thin	187,733	34,345	31,264	−9.0		
595	III, maintenance	230,275	36,555	35,521	−2.8		
525	III	265,587	39,955	38,834	−2.8		
524	III	322,234	46,417	43,822	−5.6		
509	III	391,461	49,701	49,490	−0.4		
500	III	407,833	54,148	50,770	−6.2		

[a] This is given as 0.134 in the original paper. The author later substituted for 0.134 the constant 0.158.

It is necessary to consult the original paper to obtain a detailed description of the steers, but the following excerpt will explain the significance of the groups. "Group I was full fed and crowded. Group II was fed for maximum growth without laying on appreciable fat. Group III was fed for retarded growth—about one-half pound gain daily when yearlings." (*14, p. 6.*)

Since the formulae were derived from the weights of these animals, the circumstances are especially favorable for obtaining good results. The agreement between the calculated and observed values of the Group I animals is very close indeed. Groups II and III diverge somewhat more. Presumably, that is due to the fact that the steers in Group I were quite uniform, while those in Groups II and III varied widely in condition. In Group I the maximum errors are + 2.8 per cent and − 5.6 per cent. In Groups II and III the maximum errors are + 7.4 per cent and − 9.0

per cent. We did not have measurements of some of these animals, so were unable to apply the length-weight formula to all of them. In 19 cases, however, we have the data to make a direct comparison between the Moulton and the length-weight formulae. Reference to Tables IV and VI shows that in these instances the latter formula gives a slightly smaller maximum error and a slightly smaller average error. The maximum deviations from the measured values are +5.4 and −4.8 per cent. From the Moulton formulae it is seen that the maximum deviations are +2.8 and −7.6 per cent. The averages of all errors are, respectively, 2.5 and 3.0 per cent. This comparison hardly does more than indicate that the length-weight formula is at least as accurate as any other hitherto proposed.

With all the 37 cattle whose surface areas have been calculated by our formula (Table IV) the maximum errors were less than ±5.5 per cent. With all the 33 steers whose surface areas were calculated by the original Moulton formulae (Table VI) the maximum errors were +7.4 and −9.0 per cent. The average errors were, respectively, 2.7 and 3.1 per cent. It will be recalled (Table IV) that we modified the Moulton formula so that it could be applied to the live weight. The maximum error was ±10.2 per cent, and the average error was 3.7 per cent.

A more refined statistical method is required to properly evaluate the two methods, but we do not consider such a procedure necessary. The formula we have proposed so far as it has been tested applies to all animals of the breed, and there is no opportunity for error in deciding which formula to use. Furthermore, it is more accurate than other formulae hitherto proposed.

SUMMARY

By using the weight and length of body, a more accurate formula has been developed for calculating the surface area of cattle and swine. The formula is:

$$S = W^{.4} \times L^{.6} \times K$$

S is the surface area in square centimeters, W is the weight in kilograms, L is the length of the body in centimeters, and K is the constant 217 for cattle and 175 for swine. The maximum error is less than ±5.5 per cent with either cattle or swine.

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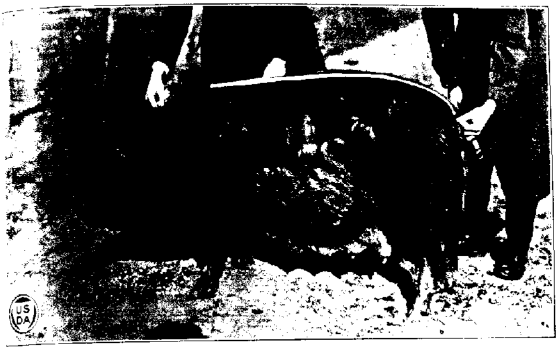
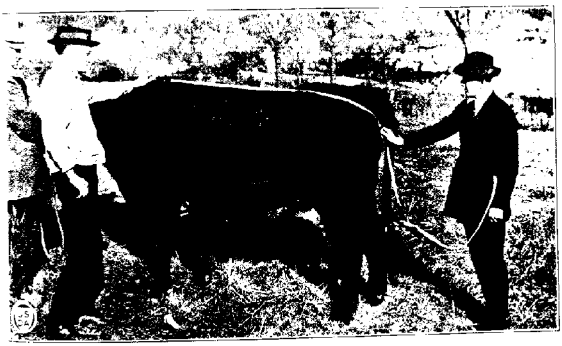
PLATE I

Method of measuring length of body of cattle and swine. The white portion o
the tape indicates length of body.





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